Feasibility Study of Integrating Remanufactured Gearboxes in Production Line of New Trucks (iReGear)

Figure: A remanufactured Scania gearbox

Författare:
Farazee M. A. Asif, Assistant Professor KTH Royal Institute of Technology

Jonny Gustafsson Researcher Engineer KTH Royal Institute of Technology

Support:

Maria Bodingh Johansson, Project Manager, Industrial Engineering Expert, Environmental Sustainable Manufacturing, Scania CV AB

Michael Lieder, Business Developer, Circular Economy Sustainability Analysis, Scania CV AB

Jenny Linde, General Manager, Scandinavian Transmission Service AB

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Final Report

Feasibility Study of Integrating Remanufactured Gearboxes in Production Line of New Trucks (iReGear)

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Innehållsförteckning

FFI in short

FFI, Strategic Vehicle Research and Innovation, is a joint program between the state and the automotive industry running since 2009. FFI promotes and finances research and innovation to sustainable road transport.

For more information: www.ffisweden.se

1 Sammanfattning

En övergång till cirkulär ekonomi (CE) har blivit nödvändig för att bemöta kommande utmaningar med brist och prisvolatilitet på resurser, samt för att minimera påverkan på klimat och miljö. Till år 2030 skulle CE kunna leda till en minskning av konsumptionen av primära material med 32 %[1], och minskning av utsläpp av växthusgaser med 48 % jämfört med 2012 års nivåer i EU[2]. Europeiska miljöbyrån[3] uppskattar att de nettofördelar för företag som uppstår genom att implementera CE ligger mellan 245 miljarder och 604 miljarder euro. Dessa siffror till trots är verkligheten ganska dyster. Återtillverkning[4], som är en av de viktigaste strategierna för att implementera CE-principer i tillverkningsindustrin, har en intensitet (kvot mellan återtillverkning och nytillverkning) på endast 1.9 %, medan intensiteten i fordonssektorn är 1.1 % inom EU[5]. Detta innebär att intensiteten för återtillverkning måste ökas avsevärt i alla sektorer for att man ska kunna utnyttja potentialen i CE.

Hos Scania och många andra Original Equipment Manufacturers (OEM) och underleverantörer (OES) hanteras flödet av nya komponenter, för produktionen av nya fordon, oberoende av flödet av återtillverkade komponenter som är avsedda för eftermarknaden. Växellådan är en sådan komponent. För att ett företag ska kunna intensifiera sin cirkularitet till den nivå som samhället behöver utan att konkurrera med eftermarknadsverksamheten är det avgörande att integrera återtillverkade komponenter i produktionen av nya produkter[6]. Trots detta har OEM-företagen hittills inte försökt att systematiskt integrera återtillverkade komponenter i de nya produkterna.

iReGear-projektet presenterar den första framgångsrika demonstrationen av att integrera en återtillverkad växellåda i produktionslinjen för nya lastbilar och fungerar som en objektiv demonstration av att en återtillverkad växellåda kan prestera lika bra som en ny. Projektet undersökte också och bekräftade att det inte finns några juridiska hinder för att använda återtillverkade komponenter i nya lastbilar, förutsatt att kunderna informeras om detta. Dessutom har det fastställts att det inte finns några befintliga exempel på att återtillverkade komponenter används i nya fordon.

Två stora Scania-kunder har sagt sig vara villiga att acceptera återtillverkade komponenter i nya lastbilar, så länge som prestanda och konkurrenskraft för lastbilarna inte äventyras. De har också visat en beredskap att betala mer för en sådan lösning, givet att den minskar de totala utsläppen, och att deras kunder är villiga att betala för dessa extra miljöfördelar.

Ett försök har också gjorts att formulera två grundläggande ekvationer och en procedur för att uppskatta den ekonomiska och miljömässiga potentialen för att skala upp användningen av återtillverkade växellådor i nya lastbilar. Dessutom uppskattas den nuvarande återtillverkningsintensiteten för växellådan vara endast 0,4 % i förhållande till antalet nya växellådor som produceras av Scania varje år, vilket indikerar en betydande potential för att kunna öka volymen av återtillverkade växellådor.

Denna forskning ger ett betydande bidrag till den pågående diskussionen och ett första bevis som stöd för argumentet att det är genomförbart för framtida tillverkningsorganisationer att sömlöst integrera tillverknings- och återtillverkningsverksamheter för att utveckla cirkulära tillverkningssystem. Dessa kommer då att konsumera färre resurser, producera färre utsläpp och kosta mindre utan att kompromissa med kvalitet och prestanda. Framtida forskning bör fortsätta med en vision mot ett cirkulärt tillverkningssystem, där integrationen av återtillverkade komponenter blir normen. Under resans gång bör insatser också fokusera på att förbättra effektiviteten i återtillverkning genom att åtgärda bristerna i konventionella metoder.

2 Executive summary

The transition towards a circular economy (CE) has become inevitable to mitigate challenges of resource scarcity and resource price volatility, as well as minimize the climate and environmental impact. By 2030 for the EU, CE could result in a reduction of primary material consumption by 32% [1] and greenhouse gas emissions by 48 % compared with the 2012 levels[2]. The European Environment Agency[3] estimates that the net benefits for businesses by implementing CE measures range from EUR 245 billion to EUR 604 billion. Although these figures are promising the reality is rather bitter. Remanufacturing[4] which is one of the most important strategies in implementing CE principles in the manufacturing industry, has an intensity (ratio of remanufacturing to new manufacturing) of only 1.9%, while the intensity in the automotive sector is 1.1% in the EU[5]. This means that the remanufacturing intensity in all sectors needs to be increased significantly to exploit the untapped potential of CE.

At Scania and many other Original Equipment Manufacturers (OEMs) and Suppliers (OESs), the flow of new components for the production of new vehicles is handled independently from the flow of remanufactured components that are intended for the aftermarket. The gearbox is one such component. For any company to intensify its circularity to the level that society needs without cannibalising the aftermarket business, integrating remanufactured components in the production of new products is essential[6]. However, OEMs have thus far not attempted to systematically integrate remanufactured components in the new products.

The iReGear project presents the first successful demonstration of integrating a remanufactured gearbox into the production line of new trucks and serves as an objective demonstration that the remanufactured gearbox performs as good as a new one. The project also investigated and confirmed that there are no legal obstacles to using remanufactured components in new trucks, provided that customers are informed about it. Additionally, it has been established that there are no existing examples of remanufactured components being used in new vehicles.

Two major Scania customers have indicated their willingness to accept remanufactured components in new trucks, as long as the performance and competitiveness of the trucks are not compromised. They also expressed a readiness to pay more for such a solution, given that it reduces overall emissions, and their customers are willing to pay for these added environmental benefits.

An attempt has also been made to formulate two basic equations and a procedure to estimate the economic and environmental potential of scaling up the use of remanufactured gearboxes in new trucks. Moreover, it is also estimated that the current remanufacturing intensity of the gearbox is only 0.4% relative to the number of new gearboxes produced by Scania each year indicating a significant potential for increasing the volume of remanufactured gearboxes.

This research makes a significant contribution to the ongoing discussion and provides the first evidence to support the argument that it is feasible to envision future manufacturing organizations seamlessly integrating manufacturing and remanufacturing operations to develop Circular Manufacturing Systems that consume fewer resources, produce fewer emissions, and cost less without compromising quality and performance. Future research should advance with a vision toward a Circular Manufacturing System, where the integration of remanufactured components becomes the status quo. Along the way, efforts should also focus on enhancing the efficiency of remanufacturing by addressing the shortcomings of conventional approaches.

Keywords: Circular Manufacturing Systems; Circular Economy; Remanufacturing; iregear; Scania

1 Ellen MacArthur Foundation, n.d. The circular economy in detail, Deep dive [WWW Document]. URL https://ellenmacarthurfoundation.org/the-circular-economy-in-detail-deep-dive#:~:text=The (accessed 3.8.23).

2 McKinsey, 2015. Europe's circular economy opportunity. McKinsey& Co. 1–7.

3 European Environment Agency, 2016. Circular economy in Europe - developing the knowledge base, Publication Office of the Euopean Union.

4 Remanufacturing is not the same as reparing, recycling or refurbishing. It is about reusing components of an existing product to create a new product with a full warranty, to be sold as new or remanufactured. They are almost indistinguishable from new parts.

5 Parker, D., Riley, K., Robinson, S., Symington, H., Tewson, J., Jansson, K., Ramkumar, S., Peck, D., 2015. Remanufacturing Market Study, European Remanufacturing Network. https://doi.org/EC--09 404 ERN WP2.2.docx

6 Rashid, A., Asif, F.M.A., Krajnik, P., Nicolescu, C.M., 2013. Resource conservative manufacturing: An essential change in business and technology paradigm for sustainable manufacturing. J. Clean. Prod. 57. https://doi.org/10.1016/j.jclepro.2013.06.012

3 Background

The transition towards a circular economy (CE) has become inevitable to mitigate challenges of resource scarcity and resource price volatility, as well as minimize the climate and environmental impact. By 2030 for the EU, CE could result in a reduction of primary material consumption by 32%[1] and greenhouse gas emissions by 48 % compared with the 2012 levels2. The European Environment Agency[3] estimates that the net benefits for businesses by implementing CE measures range from EUR 245 billion to EUR 604 billion. Although these figures are promising the reality is rather bitter. Remanufacturing which is one of the most important strategies in implementing CE principles in the manufacturing industry, has an intensity (ratio of remanufacturing to new manufacturing) of only 1.9%, while the intensity in the automotive sector is 1.1% in the EU[5]. This means that the remanufacturing intensity in all sectors needs to be increased significantly to exploit the untapped potential of CE.

At Scania and many other Original Equipment Manufacturers (OEMs) and Suppliers (OESs), the flow of new components for the production of new vehicles is handled independently from the flow of remanufactured components that are intended for the aftermarket. The gearbox is one such component. For any company to intensify its circularity to the level that society needs without cannibalising the aftermarket business, integrating remanufactured components in the production of new products is essential[6.] However, OEMs have thus far not attempted to systematically integrate remanufactured components in the new products.

4 Purpose, research questions and method

The purpose of this research is to demonstrate that it is feasible to envision future manufacturing organizations seamlessly integrating manufacturing and remanufacturing operations to develop Circular Manufacturing Systems that consume fewer resources, produce fewer emissions, and cost less without compromising quality and performance.

Aligned to this purpose, a pre-study project, iReGear was launched to create new knowledge by testing the hypothesis that *"the integration of remanufactured gearboxes in the production line of new trucks is technically possible and legally allowed while meeting all standards (e.g., safety, reliability and customer acceptance) as of a newly produced gearbox."*

This hypothesis is broken down into the following research questions:

1. How can a remanufactured gearbox be physically and virtually integrated into the production line of new trucks?
2. Is the remanufactured gearbox 'as good as' new?
3. Is it legally permissible to use remanufactured gearboxes in new trucks?
4. What are customers' perceptions of using remanufactured gearboxes in new trucks?
5. Are there examples of using remanufactured components in new products in the automotive and other sectors?
6. What is the economic and environmental potential of using remanufactured gearboxes in new trucks?

A qualitative research approach is adopted to test the hypothesis by answering these research questions. Given that the research focuses primarily on exploring existing knowledge and theories, focus groups and individual interviews with domain experts are considered the most appropriate methods. A semi-structured approach with predefined goals and questions is used to guide the interviews while allowing ample room to incorporate relevant insights. For the literature review, Internet Search is utilized, as the review focuses specifically on legal aspects and industrial best practices, making Internet Search a sufficient tool. To calculate the carbon

footprint, a fast-track cradle-to-gate lifecycle assessment is conducted. Additionally, simple analytical models are developed to estimate the economic and environmental potential of scaling up the use of remanufactured gearboxes in new trucks.

5 Objective

The project aimed at unfolding new knowledge through a feasibility study integration of remanufactured gearboxes in the production line of new trucks is technically possible and legally allowed while meeting all standards (e.g., safety, reliability and customer acceptance) as of a newly produced gearbox.

The project has successfully investigated the feasibility of integrating a remanufactured gearbox into the production line of new trucks. In doing so, it examined technical feasibility (e.g., safety, quality, and reliability), legal aspects, and customer acceptance.

To test the technical feasibility, the project demonstrated that seamless integration of remanufactured components in the production line of new trucks is possible without disrupting production. Furthermore, a remanufactured gearbox underwent testing on the same rig used for new gearboxes, monitoring about 100 parameters. These tests objectively confirmed that a remanufactured gearbox is 'as good as new' based on new production quality standards.

Regarding legal aspects, the project reviewed more than fifty different directives, regulations, laws, and articles, confirming that there are no legal obstacles to using remanufactured components in new trucks as long as customers are informed about it.

Two major customers of Scania were interviewed to understand their perspectives on accepting remanufactured gearboxes in new trucks. Both customers indicated their willingness to accept remanufactured components in new trucks as long as it does not compromise the trucks' performance and competitiveness. They also expressed readiness to pay more for such a solution, given that it reduces overall emissions, and their customers are willing to pay for environmental benefits. Additionally, an attempt has also been made to formulate two basic equations and a procedure to estimate the economic and environmental potential of scaling up the use of remanufactured gearboxes in new trucks

5.1 Disclaimer

The iReGear project is driven by a vision of a Circular Manufacturing System where new and remanufactured components are seamlessly flowing in the production line. To demonstrate this, the gearbox was chosen as a case product due to its strategic value for Scania. It was assumed that the chosen gearbox type GRSO905 belongs to trucks. Later in the project, it was found that the variant 576477 of the gearbox type GRSO905 that could be integrated (based on the availability of parts and software to run the test) belongs to a bus.

The phrase ‘as good as new’ is used in this project focusing on the scope of production and production-related quality standards specific to one gearbox. It does not include durability-related analysis such as material fatigue during applications, which needs to be investigated in a separate study.

However, this doesn’t influence the outcomes of this project and the goal that was intended to achieve. We continue to refer to ‘truck’ to remain consistent with the project proposal submitted to Vinnova.

6 Results

6.1 Technical Feasibility

The project investigated the feasibility of integrating remanufactured gearboxes into the production line of new trucks in two key aspects. Firstly, it assessed the technical feasibility of physically integrating a remanufactured gearbox into the assembly line. Secondly, the project tested the remanufactured gearbox on the same test rig as a new gearbox. The process took place on May 29, 2024, between 8:00 AM and 11:30 AM at Scania. The sections below highlight the process, key aspects, and challenges of this integration.

6.1.1 Integrating the Remanufactured Gearbox

Since interrupting production for integration and testing through a trial-and-error process was not an option, the project required a seamless integration on the first attempt. Consequently, extensive time was dedicated to planning and preparation. This involved the physical integration of a remanufactured gearbox into the production line and the virtual integration within the IT system, which can trigger the physical flow, including the flow of necessary parts to assemble the gearbox. To virtually integrate the gearbox into the IT system, an order was created to trigger the assembly process for the remanufactured gearbox. Identifying the correct variant of the gearbox was crucial for this process. Gearbox 576477 was selected as the most suitable variant for integration, based on the availability of the necessary parts. It was ensured that Scandinavian Transmission Service AB (STS AB) would supply the same variant (i.e., 576477) of the remanufactured gearbox for integration. It's important to note that gearbox variant 576477 is designed for a Scania bus, not a truck as initially proposed by the project. Refer to the Disclaimer section for more details.
Note that the chosen variant is no longer in production. Therefore, to initiate the physical flow of the remanufactured gearbox, an old order for the chosen variant was copied and entered into the production planning IT system. The remanufactured gearbox was tested with the same software program that is used to test new gearboxes in production.
Following the virtual integration, the first step in the physical integration was to identify the location (assembly station) where the remanufactured gearbox would enter the assembly line. The gearbox received from STS AB is in a similar state to a ‘Grund låda’ (base gearbox) after HASA, which was identified as the optimal entry point (see Figure 1). The gearbox was then placed on an automated guided vehicle (AGV) to transport it to the main line. The red dot indicates the exact location where the remanufactured gearbox entered the assembly line.

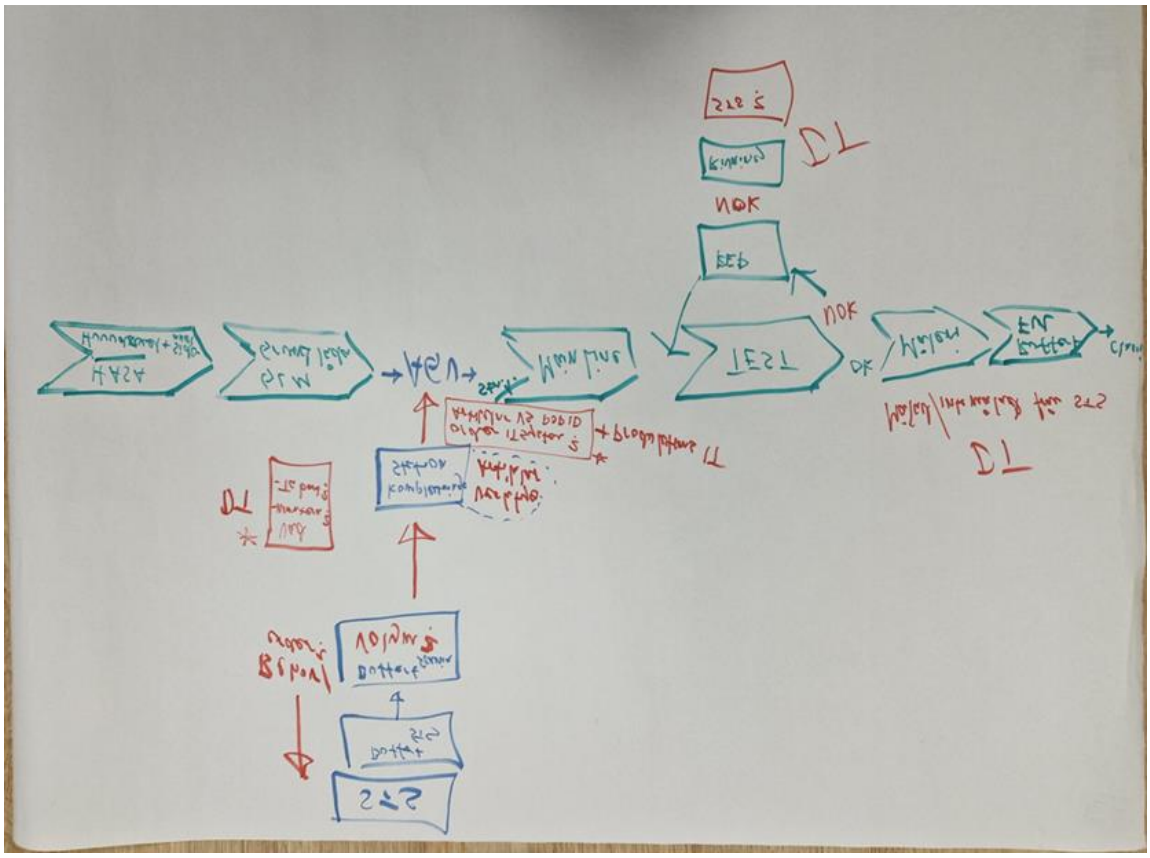

Figure 1: A schematic of the flow of remanufactured gearbox integration (courtesy: Christer Wilhelmsson)

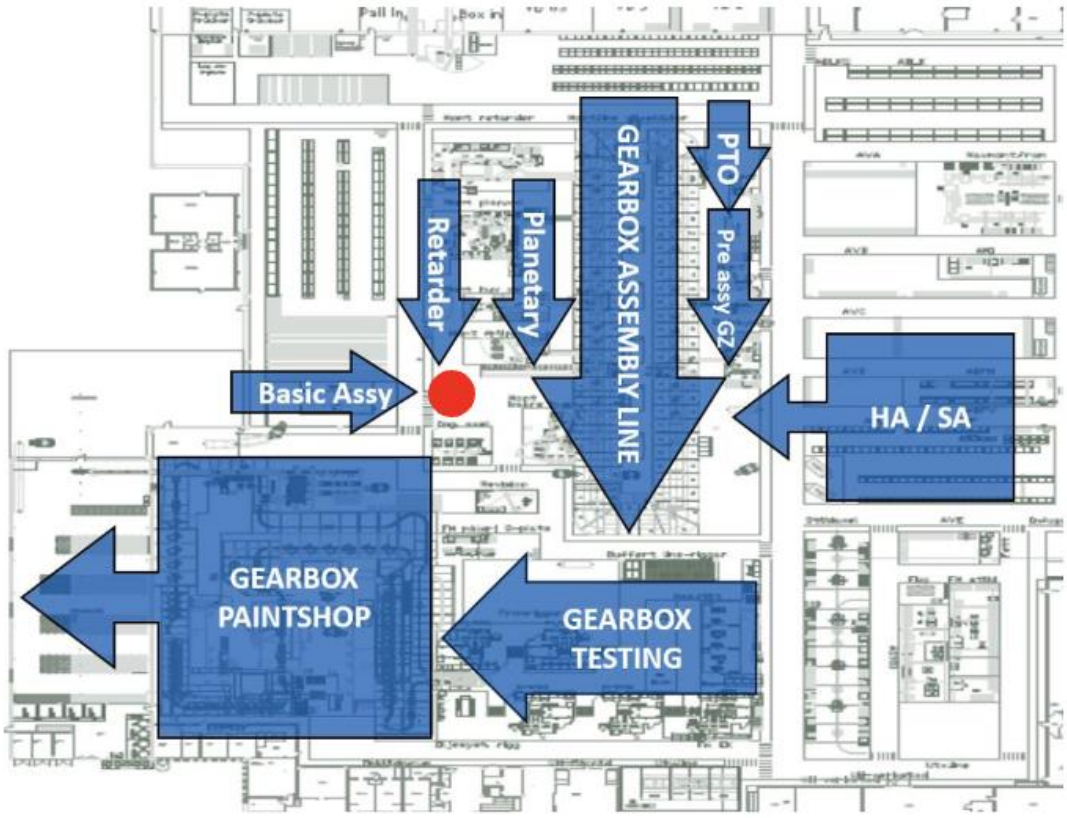

Figure 2: Layout of the gearbox assembly at DT. The red dot in the layout shows the location where the remanufactured gearbox entered the assembly line (courtesy: Scania).

Since the remanufactured gearbox provided by STS AB was not exactly in the same state as the base gearbox, adaptations were necessary. Therefore, an adaptation station was set up (see Figure 3). During this step, unnecessary parts were removed, and essential components were assembled to match the base gearbox configuration. To determine which parts needed to be added or removed, the POP ID from production was extracted, and the adaptation and assembly were completed accordingly.

Figure 3: A temporary adaptation station (courtesy: Scania).

Figure 4: An operator placing the gearbox on an AVG (courtesy: Scania).

After adaptation, the gearbox was placed on the AGV for transport to the main line (see Figure 4 and Figure 5). Once transported, the gearbox was mounted onto a carrier on the main line by an operator using lifting equipment, as shown in Figure 6.

Figure 5: The AVG transporting the gearbox to the main line (courtesy: Scania).

Figure 6: An Operator is lifting the gearbox from the AVG and mounting it on a carrier in the main line (courtesy: Scania).

Afterwards, the gearbox proceeded through the entire main line and was assembled in the same way as a newly produced gearbox. The only exception was that the gearbox did not undergo bearing play adjustments, as this had already been completed by STS AB. Figure 7, Figure 8, Figure 9 and Figure 10 capture snapshots of the assembly process.

Figure 7: The gearbox on its way to the first assembly station. (courtesy: Scania)

Figure 8: Assembly of the planetary gear, control unit and the back cover. (courtesy: Scania)

Figure 9: The gearbox after the assembly of the cable harness. (courtesy: Scania)

Figure 10: The gearbox is nearing the end of the main line. (courtesy: Scania)

6.1.2 Testing the Remanufactured Gearbox

After completing all assembly steps in the main line, the remanufactured gearbox was tested using the same test rig used for new gearboxes, which measured about 100 different parameters. Figures Figure 11 and Figure 12 show the snapshots of the test run.

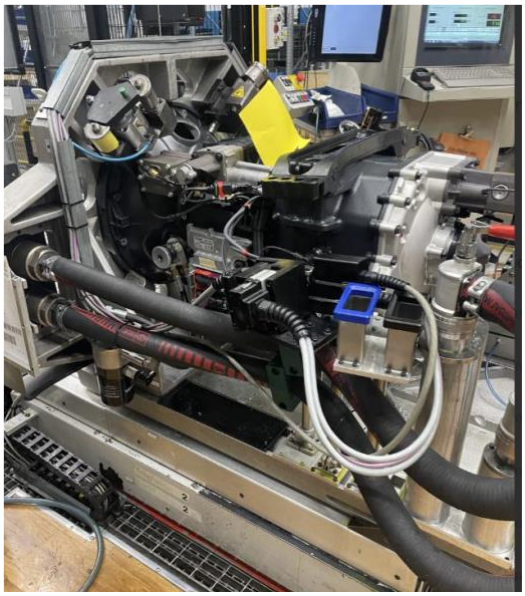

Figure 11: The gearbox is placed on the test rig pallet for the test run. (courtesy: Scania).

Figure 12: The gearbox is going through the test run using the same test program as the new gearboxes. (courtesy: Scania).

Figure 13 displays a screenshot of the test results for the remanufactured gearbox. As illustrated, the gearbox passed all tests on the first attempt, confirming that a remanufactured gearbox performs as good as a new one.

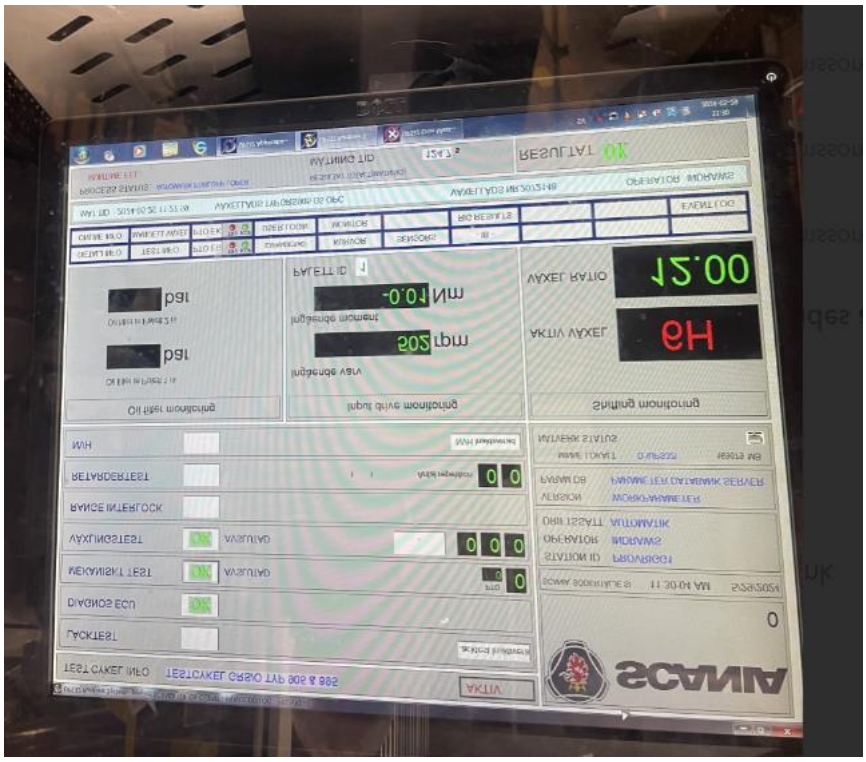

Figure 13: A screenshot of the test results for the reamn. gearbox (courtesy: Scania).

After testing, a rework request was manually entered into the IT system for the gearbox, and a red paper that indicates a rework sign was attached to the gearbox to remove it from the main line.

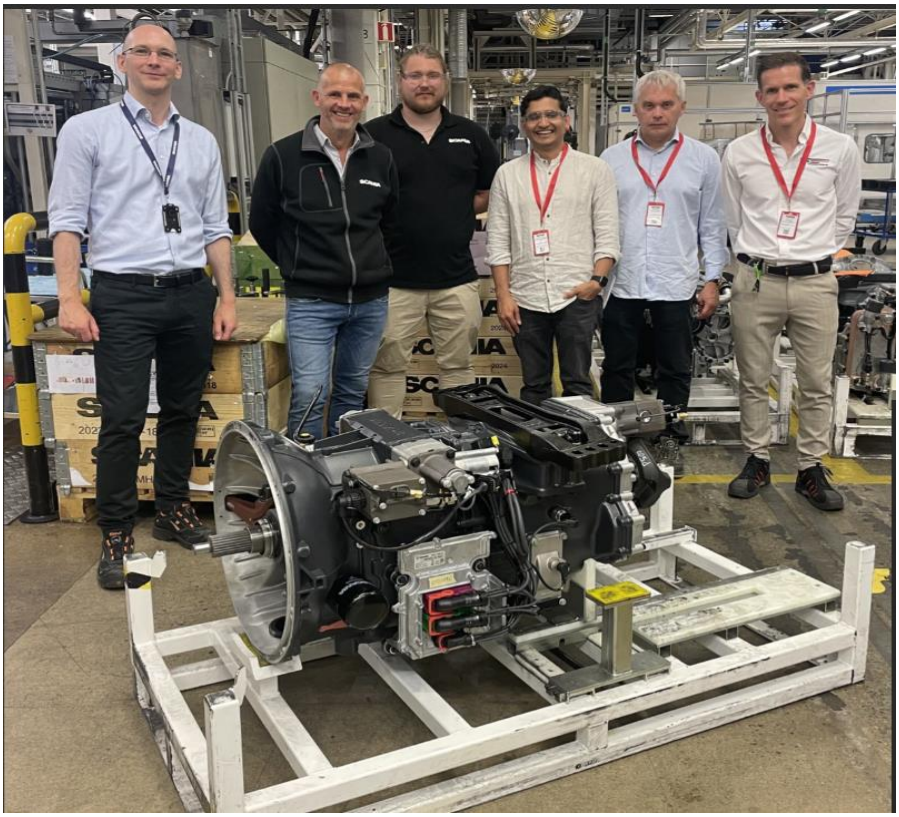

Figure 14: A few members of the project team who witnessed the event are standing behind the remanufactured gearbox that has completed the integration and testing process (courtesy: Scania).

6.1.3 Challenges with the Integration and Testing

The integration and testing faced a few minor challenges, which are highlighted below.

The first challenge was ensuring that the order reached the main line without the actual gearbox being produced or assembled. After the order was initiated and sent into production, the operators helped to “bypass” the pre-assembly work at the stations where no work was performed. Since the variant (i.e., 576477) of the remanufactured gearbox was not in production; another issue was ensuring that the right parts were available at the correct stations during the assembly. The people involved in this experiment were highly skilled and experienced, and everything went almost as planned, except for one oversight: a bracket that was supposed to have been assembled was missed. This issue was resolved with minimal impact but demonstrates how easy it is to overlook such details.

All remanufactured gearboxes are tested at STS AB before being delivered to Scania. During testing, the gearboxes are filled with gear oil, which is removed before delivery. However, even after STS AB removed the oil, some residue remained in the system. Before integration, another attempt was made to drain the remaining oil, but it was not entirely successful. As a result, oil continuously dripped onto the floor, which is considered hazardous according to standard work conditions. To prevent accidents, a person was assigned to continuously wipe off the oil from the floor.

One of the objectives of the experiment was to make it as realistic as possible. Therefore, the assembly colleagues were not informed about the experiment beforehand. This approach allowed the project team to observe whether the assembly colleagues could detect any anomalies in the integration process, thereby validating that the integration was seamless. It should be noted that only one minor anomaly was detected by a few assembly colleagues. After remanufacturing, each gearbox receives a new article number engraved on a metal plate, which is attached to the gearbox with red glue. When the remanufactured gearbox was integrated into the main line, this plate was removed. However, red glue residue remained on the gearbox, raising concerns among a few workers who noticed this anomaly.

One person was assigned to monitor the gearbox from the start of the in-line integration until it was removed from the line. This individual was tasked with addressing any concerns that might arise during the experiment, such as the issue with the glue mentioned earlier, and closely observing the integration process.

6.2 Legal Aspects

To ensure that there are no legal obstacles to using remanufactured gearboxes in new trucks a comprehensive review of more than 50 Swedish and European legal documents has been done. In addition, one of Scania’s legal advisors was interviewed to get an overview of the legal landscape in this context and verify the findings. Appendix A lists the documents that have been reviewed. The information below highlights some of the key findings of this review. Although the study focused on the gearbox as a product and Scania as the manufacturer, the findings may apply to any products and any manufacturers of similar kinds. Further, note that the contents herein are the view and interpretation of the studied documents by the authors.

The research started with the assumption that there might be some legal obstacles that would completely or partially prevent the use of remanufactured components in new trucks. It is interpreted from the studied documents and the interview with a legal advisor that there are no restrictions on using remanufactured components in new trucks. In fact, most EU regulations explicitly and implicitly encourage reuse and remanufacturing.

For example, the new Circular Economy Action Plan[7] published by the European Commission in 2020 explicitly promotes increased recycled content in products, enabling remanufacturing and high-quality recycling, and restricting single-use as well as countering premature obsolescence. The Ecodesign[8] directive evolved from using statements such as “member states shall take the

7 https://eur-lex.europa.eu/resource.html?uri=cellar:9903b325-6388-11ea-b735-01aa75ed71a1.0017.02/DOC_1&format=PDF

8 https://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=OJ:L_202401781

necessary measures to encourage reuse" to stating that products should be designed to improve, among other things, the "possibility of remanufacturing and recycling." A similar trend is seen in the revision of the End-of-Life Vehicle Directive[9], which states that vehicles should be constructed to be 85% recyclable/reusable and 95% reusable/recoverable. It also states that authorized treatment facilities should "carefully assess and determine whether parts and components are fit for reuse, remanufacturing, or refurbishment." Gearboxes are on the list of components that are mandatory to remove to promote reuse, remanufacturing, or refurbishing. The trucks with remanufactured components in them, just as other new trucks, must fulfil the requirements in existing type approvals and other certificates that ensure that a vehicle or a component type meets the applicable technical requirements. The Swedish law in this regard is interpreted as that remanufactured components can be used in vehicles if they do not affect taxation, security, environment or public health. Although the law mainly relates to using remanufactured components for repairs, it can be seen as an indication of what is valid also for new vehicles.

Another important aspect to consider when using remanufactured components in new products is the regulation concerning *misleading omission*[10]*.* The generic interpretation of this regulation is that the consumer must be informed about the use of remanufactured components in the products. Since this is not a common practice, this information might affect the *transactional decisions*[10] of an average consumer and thereby is relevant in the context of *Marketing and Omission of Information*[10]*.* The Swedish law in this regrad states that *"En näringsidkare får inte heller utelämna väsentlig information i marknadsföringen av sin egen eller någon annans näringsverksamhet*[11]*"*

The above findings are in line with the advice of one of Scania's legal advisors. The advice includes that Scania needs to be transparent and clear with its customers about the content of remanufactured components when used in new trucks. Scania must also restore the products to the specifications of the newly manufactured trucks when they were sold.

Furthermore, remanufactured components must comply with other relevant regulations such as REACH and POP etc. A material compliance check has to be done for the material in the remanufactured component and also for the materials/parts used to replace worn-out parts in the remanufactured component. For example, if an old component contains substances that have been prohibited later, it must not be remanufactured and put back into use.

6.3 Customers' Perceptions

To gather information on customers' perceptions about using remanufactured gearboxes in new trucks, two of Scania's business-to-business customers were interviewed. It was agreed that the outcomes of the interviews would be anonymized to maintain confidentiality. Semi-structured interviews were conducted using an interview protocol (see Appendix B), which was supplied to the interviewees beforehand. Each interview lasted about an hour. After the interviews, the information was transcribed and shared with the interviewees for review.

In general, both customers are positive about using remanufactured gearboxes in new trucks and recognize this approach as important for reducing environmental impacts, as long as technical integrity is maintained. However, there are some concerns and differences in point of view, which are highlighted below.

Since both customers are in the logistics business, emissions during the use phase of the trucks are important to them and their customers. Both customers expressed that the main reason for choosing Scania as their supplier is Scania's ability to provide market-leading, high-performance products that are continuously developed to reduce emissions during the use phase. They expressed concerns that if the use of remanufactured gearboxes in new trucks increases

9 *https://environment.ec.europa.eu/publications/proposal-regulation-circularity-requirements-vehicle-design-and-management-end-life-vehicles_en*

10 *Directive 2005/29/EC or the European parliament and of the council of 11 May 2005 concerning unfair business-to-consumer commercial practices, Article 7, https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX:32005L0029*

11 *Marknadsföringslag (2008:486), §10, https://www.riksdagen.se/sv/dokument-och-lagar/dokument/svensk-forfattningssamling/marknadsforingslag-2008486_sfs-2008-486/.*

emissions during the use phase, it will negatively impact their environmental performance and that of their customers.
Interviewee A concluded that reducing emissions by using remanufactured gearboxes in new trucks concerns scope 3 emissions for them, which do not improve their environmental performance and therefore are not a priority for them. Interviewee A also assumed that using remanufactured components in new trucks would reduce manufacturing costs for Scania and expects that in such cases, Scania should reduce the price of the trucks.
Interviewee B, on the other hand, sees sustainability and the reduction of emissions as collective and systemic efforts, where the reduction of emissions at any phase is equally important. Although using reman gearboxes in new trucks refers to scope 3 emissions for them too, it is vital for the sustainability of the whole value chain. Interviewee B also expressed that if Scania can provide proof (for example, in the form of certification or supporting documents) that trucks with remanufactured components emit fewer emissions than trucks with only new components, this could be used to promote sustainability in the entire value chain, which could also be a competitive advantage. Interviewee B also sees sustainability as a complex issue, given that new technologies and alternative fuels are emerging, and legislation is getting tougher. Therefore, every possibility to reduce impacts is important to remain competitive.
One purpose of the interviews was to assess under which circumstances the interviewees would be willing to pay more for an environmentally better-performing product, provided that the operational performance remains intact. Both interviewees confirmed that cost is still the main key performance indicator in the logistics business, and therefore, highly efficient trucks that generate high economic value are the main priority. Reduction of emissions is the second priority in the logistics business. However, if their customers are willing to pay more for logistics services provided by trucks that are more environmentally friendly (i.e., contain remanufactured components), they would be happy to pay more for such trucks. The bottom line is to remain competitive in both cost and sustainability in a balanced manner.

6.4 Best Practices

The use of remanufactured components in new products is not a known practice.
Remanufactured components are usually sold as spare parts and remanufactured products (that combine used or remanufactured components with new components) are usually sold with a clear distinction. For example, Ricoh labelled its remanufactured printers as “Greenline” in Europe and USA[12]. However, to make an objective conclusion about whether there are examples of using remanufactured components in new products a rather comprehensive review of existing examples has been done.
The focus of this review has been the automotive sector, especially heavy-duty vehicles. However, as the review continued some sectors repeatedly appeared as good examples of remanufacturing. These sectors are electric and electronics, heavy machinery and aerospace.
We have concluded that there are no examples found that claim to be using remanufactured components in new products and selling the products declared as new. Remanufactured products are either declared as remanufactured or labelled as a different product category (often promoted as a sustainable brand) than the usual products. In the automotive, heavy machinery and aerospace sectors it is most common that remanufactured components are sold as spare parts. In the electronics sector, especially printers, remanufacturing is quite an established concept that ranges from remanufactured cartridges to entire printers[13]. In this sector, it is rather common that remanufactured printers are offered as an alternative to the new product ranges.
Nevertheless, there may be a shift in the automotive sector and in the near future remanufactured vehicles can be an available alternative. For example, Toyota’s plan to remanufacture cars to be

12 Akira Oyama. Ricoh Group Circular Economy Report 2023. Ricoh Com- pany, 2023.

13 Mitsutaka Matsumoto and Yasushi Umeda. “An Analysis of Remanufac- turing Practices in Japan”. In: Journal of Remanufacturing 1.2 (2011), pp. 1–11

used in the Kinto program[14], which includes short-time rental, subscription-based leasing and carpooling as well as the ambition of Renault's first circular economy factory[15] in Europe can be considered as the beginning of this shift.

6.5 Economic and Environmental Potential of Scaling Up

This section briefly discusses the positive economic and environmental impacts that could be achieved by scaling up the use of remanufactured gearboxes in new trucks.

6.5.1 Economic Potential

This section elaborates on the economic and environmental potential of using remanufactured gearbox in new trucks and provides a brief analysis of the scale-up effects.

Pricing of the remanufactured gearboxes is done in a two-step process based on a cost-based pricing approach. This cost-based pricing is built on five cost categories: material, labor, process, other, and overhead.

The first step involves estimating the cost of remanufacturing a component. For components (specific article numbers) that have not been remanufactured before, a thorough analysis is done in close collaboration with the customers. This includes identifying parts that must be replaced regardless of the condition of the cores, determining the part injection rate (i.e., an average of the exchange material from several cores), different process steps needed, and the time required to perform each process step. Combining all these factors the price of a component (a specific article number) is agreed upon and fixed for one year.

The next step involves monitoring and recording the cost of remanufacturing every component. For each remanufactured component, STS AB maintains a journal that includes the number of parts replaced, the number of process steps used, and the time spent in each process step. This provides precise and transparent information about the actual cost of remanufacturing a component. Based on this information, the actual average cost is calculated for the entire year, considering the total volume.

Furthermore, depending on the quality of cores coming from the market, the part injection rate, and the time and effort needed to remanufacture a component can vary significantly. This variation affects the actual average cost of remanufacturing a component, and price adjustments are made within the agreed time interval to ensure the price remains fair and transparent. Due to the nature of this pricing strategy as well as the significant variation in core quality, it is relatively difficult to estimate the cost of one specific gearbox.

The price (paid by an individual customer of Scania) of the remanufactured gearbox is confidential information and a strategic instrument for Scania to maintain customer relationships and competitiveness. Therefore, no further details on the difference between manufacturing and remanufacturing costs or prices could be disclosed.

The total number of components in the gearbox is 134, out of which 48 components (35%) are always replaced as per the specifications set by Scania. These replacement components represent 18% of the total cost of the material. This means the material cost of a specific gearbox may vary by 82%. In an ideal case, this 82% is the window of opportunity for material cost reduction, which is directly linked to the quality of the cores received by STS. A better quality core means higher cost-saving potential in general.

As mentioned earlier, the cost of manufacturing and remanufacturing is confidential information and therefore, the scale-up potential cannot be estimated in absolute value. However, the actual figures are available to relevant functions at Scania and STS AB, which can be used to easily estimate the economic potential of scaling up using the straightforward equation below:

14 Sbastiaen Toma. Toyota's Plan to Remanufacture Cars Is Genius Once You Think About Its Kinto Brand. 2022. url: https://www.autoevolution. com/news/toyota-s-plan-to-remanufacture-cars-is-genius-once-you- think-about-its-kinto-brand-178665.html.

15 Ellen MacArthur Foundation. Europe's first circular economy factory for vehicles: Renault. 2021. url: https://www.ellenmacarthurfoundation. org/circular-examples/groupe-renault.

$$P_{Eco} = [(C_m - C_{rm}) + C_{SavingCore}] \times \mathrm{Q}$$

Where:

- P_{Eco} is the economic potential of scaling up.
- C_m is the manufacturing cost per unit.
- $C_{rm}$is the remanufacturing cost per unit.
- $C_{SavingCore}$ is the cost-saving per unit core if the quality of the core is better controlled
- Q is the quantity of units remanufactured.

6.5.2 Environmental Potential

To calculate the carbon footprint and use that information to estimate the environmental impacts, a fast-track cradle-to-gate lifecycle assessment is conducted. The carbon footprint of a gearbox (cradle-to-gate) is estimated to be 682 kg CO2-eqv/gearbox. The gearbox that is used in this case study is estimated to be remanufactured with roughly 45 % fewer carbon emissions.
A very simplified estimation approach is used in this estimation and a detailed estimation is not within the scope of this project. A rather comprehensive study by Pranav and Mohamad (2017)[16] estimates remanufactured gearbox causes 38% less CO2 emission. The simplified and brief information above indicates that if needed accurate estimation of carbon footprint is possible, which can be extrapolated to estimate the environmental potential of scaling up using the straightforward equation below:

$$P_{Env} = [(CO_{2_m} - CO_{2_{rm}}) + CO_{2_{ReductionCore}}] \times \mathrm{Q}$$

Where:

- P_{Env} is the environmental potential of scaling up.
- CO_{2_m} is the carbon footprint of manufacturing per unit.
- $CO_{2_{rm}}$is the carbon footprint of remanufacturing per unit.
- $CO_{2_{ReductionCore}}$ is the carbon footprint reduction per unit core if the quality of the core is better controlled
- Q is the quantity of units remanufactured.

The current remanufacturing intensity of the gearbox is only 0.4% relative to the number of new gearboxes produced. This indicates a significant potential for increasing the volume of remanufactured gearboxes.

[16] Pranav Gabhane and Mohamad Kaddoura, Remanufacturing in Circular Economy: A Gearbox Example A Comparative Life Cycle and Cost Assessment Master's thesis in Sustainable Energy Systems, Chalmers University of Technology, Sweden 2017.

The project results mentioned above have contributed significantly to several objectives outlined in the FFI and FFI-Circularity roadmaps as analyzed in Table 1.

Table 1: Analysis of the project results in the context of the FFI and FFI-Circularity programme's objectives

"öka kompetensen inom, och hitta konkreta lösningar för utmaningar kopplade till cirkularitet"
The iReGear project marks the first successful demonstration of integrating a remanufactured gearbox into the production line of new trucks, providing clear evidence that a remanufactured gearbox performs just as good as a new one. The integration and testing process yielded concrete solutions that companies should adopt if they aim to scale up circularity within their organizations.
"*En robust och konkurrenskraftig produktionskedja lokalt och globalt behöver säkras"*
The project also demonstrates that collaboration between a local manufacturer (Scania) and a remanufacturer (STS AB) can create a robust circular system and establish a competitive production chain.
"nya affärsmodeller och arbetssätt kommer att behövas för att möjliggöra ett skifte mot ett cirkulärt system"
Integrating remanufactured gearboxes into the production of new trucks represents a novel approach to enhancing circularity compared to conventional remanufacturing approche in automotive sector. This strategy can create opportunities for new business models beyond the current practice of selling remanufactured components solely as spare parts.
"finns utmaningar kopplade till regelverk och standarder"
The project assessed the relevant legal frameworks and concluded that there are no legal barriers to using remanufactured components in new trucks. During this process, it was discovered that the revised ELV directive may compel or motivate vehicle manufacturers to facilitate reuse and remanufacturing, or even undertake these activities themselves.
"fordonsföretag inom några år har gemensamma principer för att beräkna utsläpp avseende tillverkning/skrotning av fordon och kan redovisa detta öppet"
Successful integration may inspire other actors in the sector to follow suit. As more stakeholders collaborate, a new approach to estimating emissions is expected to emerge.
"Förändrade krav och beteenden från kunder kopplade till mobilitet ställer nya krav på produkter"
Insights from consumer perceptions gathered during the project provided a clearer understanding of their needs and suggested how to effectively communicate the use of remanufactured parts in new products from a consumer perspective.

7 Conclusions and future research

The iReGear project presents the first-ever attempt to investigate the feasibility of integrating a remanufactured gearbox into the production line of new trucks. This project has successfully demonstrated that such integration is possible without major disruptions to the production line. Although the integration was an experiment, it was conducted as realistically as possible, providing sufficient knowledge and confidence that mass integration is feasible. Test results have shown that the remanufactured gearbox is 'as good as new' based on new production quality standards. Despite the successful integration and promising results, the question remains whether these results will remain consistent if mass integration is implemented at Scania. It must be appreciated that the project has demonstrated the feasibility of creating a manufacturing organization that seamlessly integrates manufacturing and remanufacturing operations to develop Circular Manufacturing Systems. Such integration has always been discussed and questioned within the context of the CE theories and practices but has never been attempted to verify or falsify until now. Although one example may seem too few, it is the only successful example we have, and it should hopefully encourage many others to follow this path. The technical challenges that may arise with mass integration can be overcome with systemic thinking, an experimental spirit, and, above all, a determined mindset.

The research began with the assumption that legal barriers might hinder the use of remanufactured components in new trucks. However, after reviewing more than 50 legal documents and consulting with a legal advisor, it is clear that no such restrictions exist. Numerous European Union (EU) regulations encourage the reuse and remanufacturing of components. We also conclude that significant changes are anticipated in legislation in the near future that will either implicitly or explicitly push manufacturing companies to adopt CE principles. Companies should take a proactive approach in addressing these changes and responding to societal demands for circularity.

While customers recognize the environmental benefits of using remanufactured gearboxes, they also emphasize the need for clear and transparent proof of environmental performance. Competitiveness in terms of cost and performance remains a priority for customers, but reducing environmental impacts throughout the entire value chain is highly desirable. The customers of Scania's customers are the key players in the value chain who continuously demand effective and sustainable transport solutions and will ultimately decide whether to pay more for a sustainable option.

The practice of incorporating remanufactured components into new vehicles is largely unexplored in the automotive sector, where these components are typically sold as spare parts. In contrast, the electronics sector has made more progress by offering remanufactured printers as alternatives to new ones, with clear distinctions between the two. However, a shift is anticipated in the automotive sector, where vehicles featuring remanufactured components may become more prevalent. In this context, Scania has the opportunity to be a pioneer and lead the way.

The analysis of the economic and environmental potential of scaling up the use of remanufactured components in new trucks is currently limited due to a lack of data, which is classified as confidential. It has been confirmed that relevant data is available within Scania and can be accessed if needed. To make it easy for Scania to estimate the economic and environmental potential of scaling up two straightforward but effective mathematical equations are provided. It is also worth noting that the current remanufacturing intensity is only 0.4% (the ratio of remanufactured gearboxes to new gearboxes), indicating significant potential for increasing the volume of remanufactured gearboxes.

7.1 Future work

Although the project has made significant contributions to research and practices in transitioning to a CE, it remains a drop in the ocean. There is much to be done if Scania and the manufacturing industry aim to fully exploit the true potential of CE concepts.

As the preconditions are assessed and established, a logical and desirable next step would be to make integration of remanufactured gearboxes into new trucks a standard practice—a long shot for Scania and perhaps not yet realistic but a desirable future vision for sure. It should be appreciated that the project outcomes are a few small but essential pieces of a complex puzzle, and much remains to be done to initiate full-scale integration. A systematic and systemic approach that considers critical aspects of business models, product design, supply chains, and information and communication technology is necessary for full-scale integration. A pragmatic approach for Scania would be to initiate a pilot project targeting a specific customer segment and product variant. A certain number of these product variants could be manufactured incorporating multiple remanufactured components and then sent to the market for pilot testing. It should be also noted that the primary focus has project been on legacy products which were not necessarily designed for remanufacturing to start with. In addition, the economic rationale of remanufacturing as an integrated part of manufacturing hasn't been discussed and designed in the system neither has the volumes and reverse flow management in the system. In other words, the business model of such an integrated manufacturing system has never been considered and analysed in the past. While work on managing the integration of the legacy products in volumes should continue beyond this project, it is time to start thinking in parallel of the future manufacturing systems, which are designed for circular flows which make the best business case, both from economic and environmental perspectives. This means that not only the product design, supply networks (forward and reverse) and supporting information management systems are designed for circularity but also the production lines of the future manufacturing systems should be designed for circularity. Keeping this in view, a comprehensive study on such future development will not only be an important next step but a timely one as well.

In the short term, several ideas relevant to the iReGear project could be explored. Firstly, it has been identified that currently cores (used gearboxes) are sent to STS AB without any pre-selection, resulting in a relatively high number of cores that are not suitable for remanufacturing. Implementing a pre-selection mechanism for cores based on a set of criteria could significantly improve the efficiency of the remanufacturing process.

Secondly, the usage and other relevant data associated with a core are crucial for both pre-selection and efficient remanufacturing processes. This data is also beneficial for integration, for example, to determine which spare parts are needed to complete the assembly processes. Currently, when a core is dismantled from a truck, it loses its identity, and the valuable data associated with it is completely lost. Therefore, there is a need for a component-level information management system that can collect, store, and share relevant data with the appropriate stakeholders to increase the efficiency of the remanufacturing processes.

Thirdly, STS AB does not receive any feedback on the performance of remanufactured gearboxes when they are operational in the field. While feedback on product performance is crucial for the development of next-generation products, the remanufacturing process can also benefit significantly from such insights to improve its efficiency. Investigating an information management system that could facilitate the flow of this feedback to STS AB may prove beneficial. The three proposed developments highlight the importance of tracing information at both the component and part levels and sharing it with relevant stakeholders. This approach is expected to not only improve the efficiency of the remanufacturing process but also enhance transparency in monitoring and reporting environmental impacts (such as those required by CSRD).

Finally, the revised end-of-life vehicle directives (originally developed for passenger vehicles and light trucks, now extended to include heavier vehicles as well) are expected to significantly enhance opportunities for reusing and remanufacturing vehicle components. Exploitation of this opportunity can improve economic and competitive advantages, thereby ensuring scaled-up implementation of CE practices. In this context, further research could be done to identify which truck components have the potential to be reused and remanufactured beyond those that are currently remanufactured by Scania.

8 Participating parties and contact persons

Kungliga Tekniska Högskolan

Farazee Asif *(Aorresponding Author)*
Assistant professor, Docent
e-mail: aasi@kth.se
Phone: 08 7909076

Scania CV AB

Maria Bodingh Johansson,
Project Manager, Industrial Engineering Expert,
Environmental Sustainable Manufacturing,

Scandinavian Transmission Service AB

Jenny Linde,
General Manager

9 Appendix A

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53. Ecodesign and Energy Labelling Working Plan2005/64 2022-2024 (2022/C 182/01)

54. Accompanying the document COMMUNICATION FROM THE COMMISSION Ecodesign and Energy Labelling Working Plan 2022-202

55. On a revised monitoring framework for the circular economy SWD(2023) 306 final

10 Appendix B

Research on customers' perceptions of a Sustainable Transport System of the future

Research conducted by: Farazee Asif and Jonny Gustafsson at **KTH Royal Institute of Technology**, Stockholm, Sweden in collaboration with **Scania** and **STS AB**

Purpose: *The purpose of this research is to understand how Scania can support its customers to achieve their sustainability goals.*

Background: Scania's purpose is to drive the shift towards a sustainable transport system. Scania is working on several breakthrough ideas to drive this shift. *Feasibility study of **i**ntegrating **Re**manufactured **Gear**boxes in production line of new trucks (iReGear) i*s one of the breakthrough research projects that may enable Scania to use remanufactured[17] parts (such as a gearbox) in new trucks in the future. While remanufactured components are as good as new and fulfill all quality, safety, and regulatory requirements, they also reduce material and energy consumption as well as carbon emissions significantly. For example, our research showed that by remanufacturing gearboxes we can reduce materials consumption by up to 62%, energy consumption by 63%, and carbon emission by 75%. This means the use of remanufactured components in new trucks is a critical step towards a sustainable transport system. Scania firmly believes that better collaboration with customers is essential for this journey and therefore, your contribution to the research is inevitable.

Agenda:

1. Presentation of the interviewers and interviewees
2. Brief presentation of the project and remanufacturing processes (quality, process, CO_2 and resource savings)
3. Introduction to the interview process
    a. Recording (consent)
    b. Questions
    c. Summarize
    d. Send the summary for feedback
    e. Interrupt to get through the entire protocol
4. Conduct the interview
5. Discussion and next steps
    a. Questions/comments/timeline

1. What is your view about the iReGear project?
2. Do you have questions to get further clarification about the project?
3. Briefly explain your business
4. Brief explanation of the services that you offer to your customers
5. Brief explanation of your business relationship with Scania.
6. Briefly explain your current approach to ensure sustainability.
    a. What is the drive for sustainability goals in your company?

[17] *REMANUFACTURING is the process of restoring a non-functional, discarded, or traded-in product to a like-new condition.*

    b. What are your customers demanding?
    c. What is your expectation from Scania from sustainability perspective?
7. Does your company have any plans or strategy on circular economy?
    a. What initiatives does your company have on circularity, if any?
    b. Do your customers have any demand on circularity?
    c. Do you have any expectations on circularity toward Scania?
8. What are your views on using remanufactured components in new trucks?
    a. What are your main concerns regarding this approach?
    b. What potential benefits do you see in this approach from the sustainability point of view? (*CO2 savings, communication/marketing etc.)*
    c. How do you see these benefits are aligned to your sustainability goals?
    d. Do you see any potential to align these benefits to your current/future sustainability approaches?)
9. Can you rank the level of importance in your company's purchasing decision making parameters (1,2,3) –
        a. Cost
        b. Quality
        c. Sustainable production of the product
        (*Discuss the ranking to get better understanding)*
10. Under what circumstances would you accept higher cost to compensate for environmental sustainability (CO2, material savings, other…)?